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Statistical Analysis of in-Service Evolution of an Airport Asphalt

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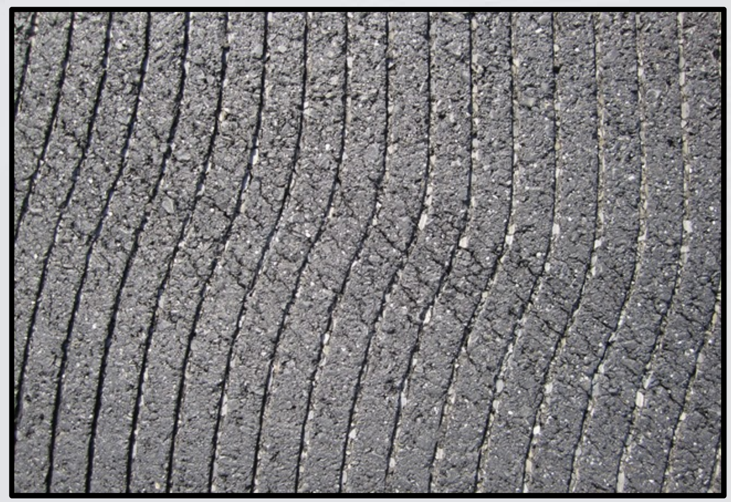
- University of Wisconsin-Madison for i-Pas 2 software

Introduction

- A broader forensic investigation into asphalt deformation
- Significant testing of trafficked and un-trafficked asphalt
- Noticed some differences between the two sets of results



Investigation Aim

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To measure the change in an asphalt surface's internal structure and response resulting from significant post-construction aircraft traffic


Background
Information

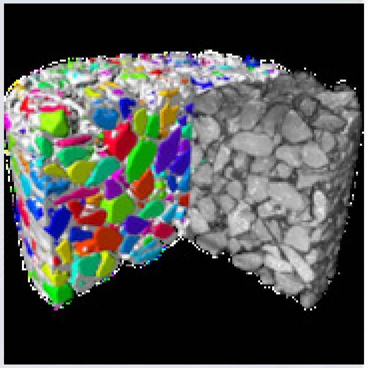
The asphalt mix

- Typical Australian Airport Marshall asphalt
- Multigrade (PPA modified) binder
- Two years old at the time of sampling
- Typical Marshall and other properties

Parameter	Mix Design Value
Binder Content (%)	5.8
Hydrated Lime Content (%)	1.0
Passing 75 µm sieve (%)	6.5
Marshal Stability (kN)	17.5
Marshal Flow (mm)	3.1
Air Voids (%)	4.2

- Additional performance parameters

Tensile Strength Ratio (%)	98
Resilient Modulus (MPa)	2,790
Indirect Diametrical Tensile Strength (kN)	960
Wheel Tracking (mm)	3.4



Aggregate skeleton characterisation

- 3D X-Ray Computer Tomography
- 2D Digital Image Analysis

Aggregate orientation

- Average Angle of Inclination – horizontalness (0 to 90°)
- Vector Magnitude – randomness (0 to 100%)
- Affected by aggregate, mix, compaction method and density

Effect of Traffic

- Limited work has been published
  - One year of traffic increased shear strength of mix
  - Density increases lead to improved bond strength
  - Aggregate re-orientates under laboratory wheel tracking
- Knowledge gaps
  - Nothing specific to aircraft traffic
  - Nothing providing multi-measures of scientific data

Investigation Methods

Basis of Comparisons

- Same Asphalt so no volumetric or production data
- Relative Density – Marshall density from Lot QA
- Resilient Modulus – Repeated Indirect Tension at 25°C
- Rut potential – Cooper's machine at 60°C for 10,000 passes
- Aggregate Orientation – Vector Magnitude and Average Angle
- Interface Shear Resistance – Strength, Modulus & Work

Aggregate Orientation

- 2D digital image analysis
- i-Pas 2 software
  - Input: image, mix volumetrics and image scale
  - Output: contact lengths, contact angles, location & angle
- Manually calculate using Curray's equations
  - Vector Magnitude
  - Average Angle of Inclination

i-Pas 2 Analysis

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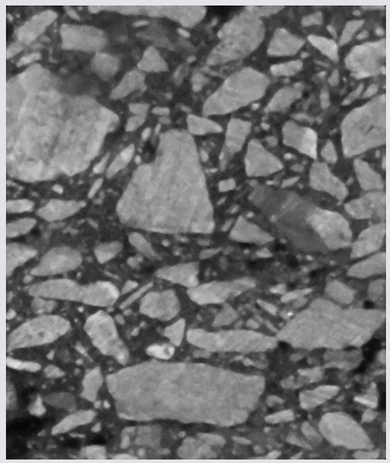

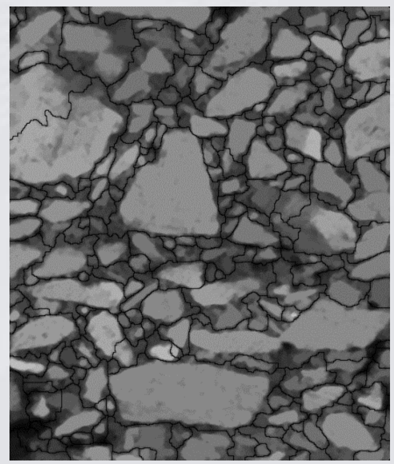

Contact Points

Location and Size

Orientation

Interface Shear Resistance

- Direct Shear in a shear-box type device
- Up to eight cubic samples from a single core
- Tested at 20-500 kPa normal stress
- Tested at 50 mm/minute deformation and 55°C
- Load and Deformation plotted against time
- Strength, Modulus and Work (to 10 mm displacement)

The Test Arrangement

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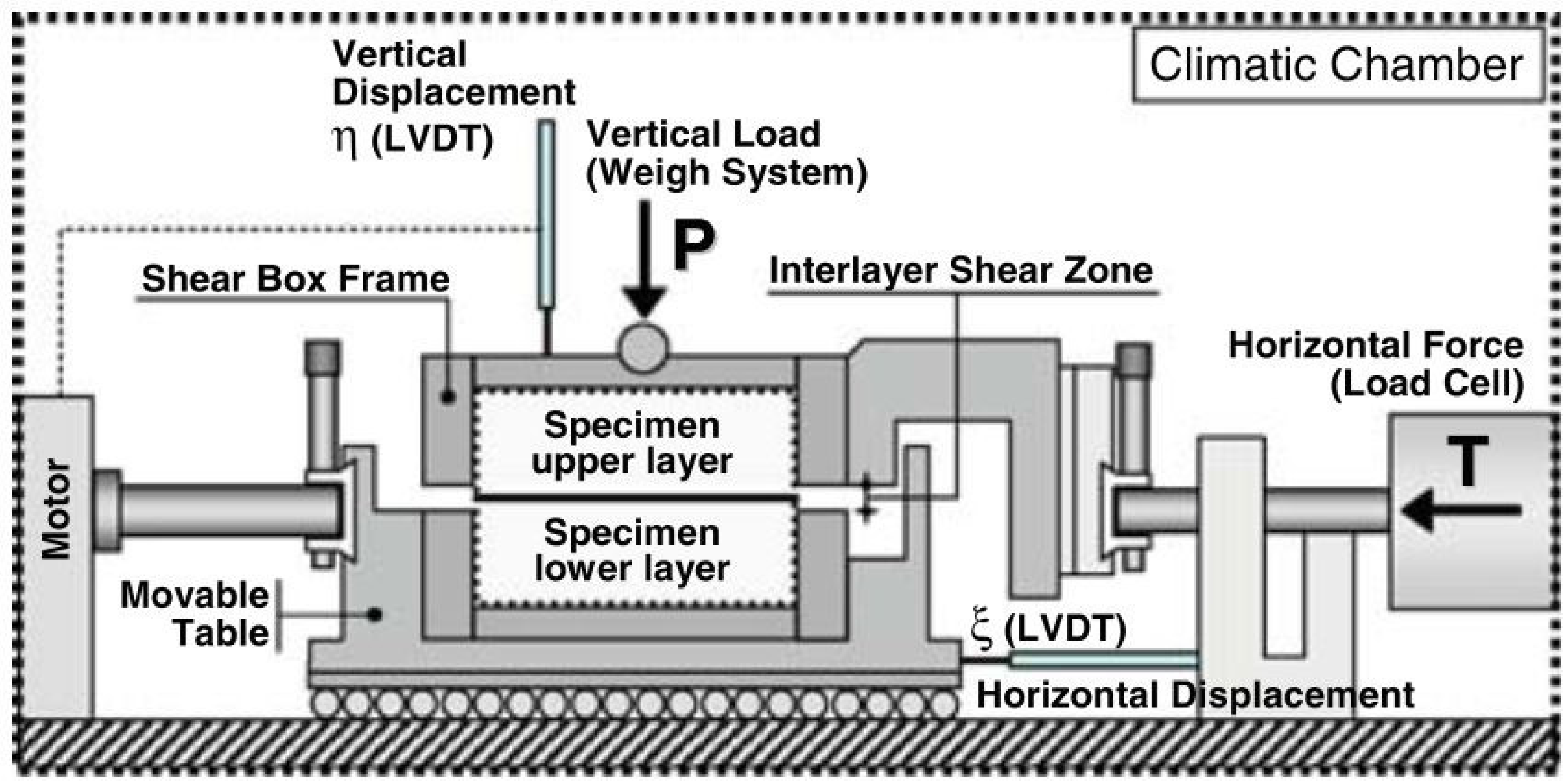

Typical Test Output

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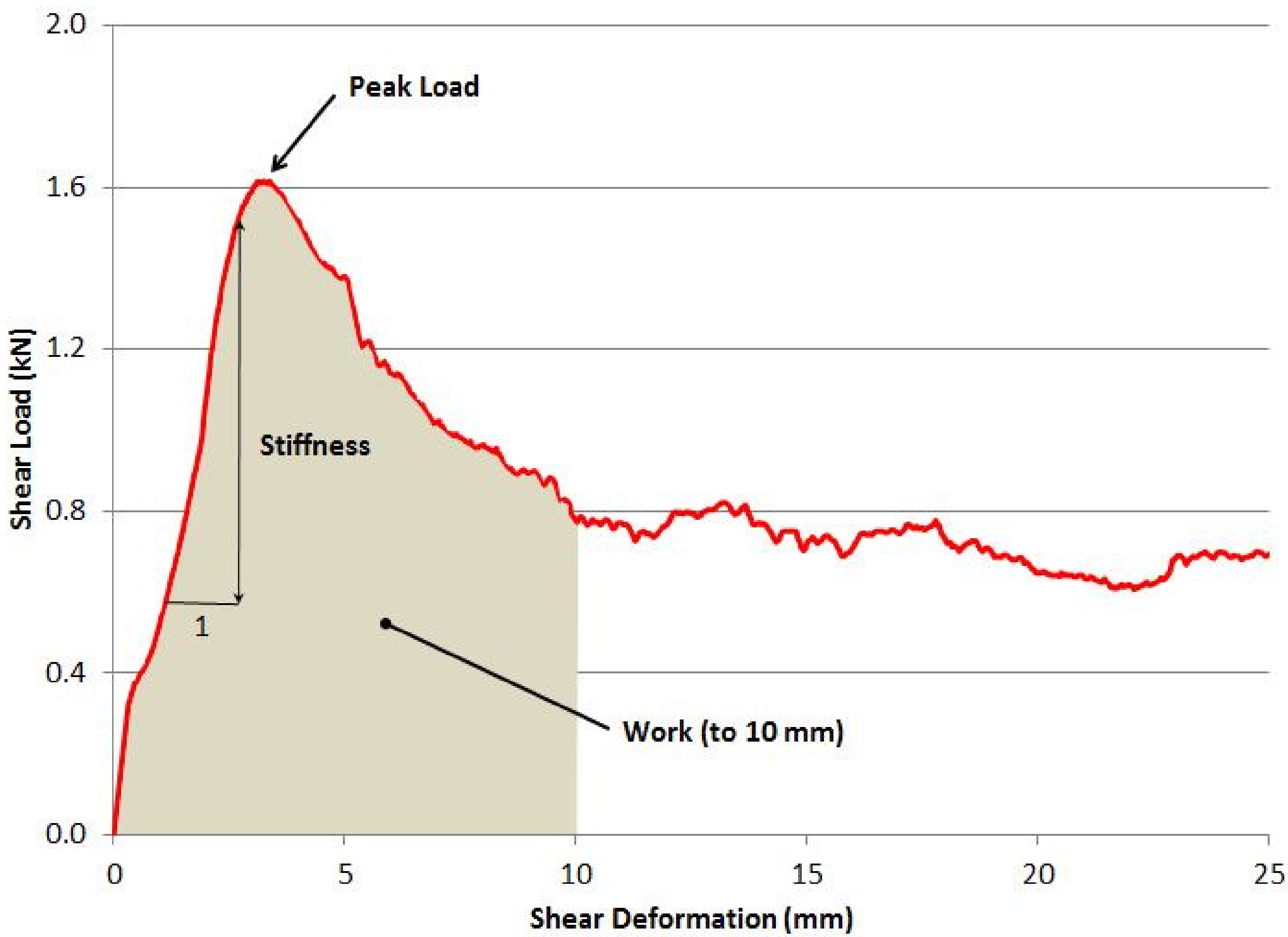

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Statistical Analysis

- For dichotomous comparisons
  - Trafficked versus Un-trafficked
  - Modulus, Density, Wheel Track & Aggregate Orientation
  - Welch's version of Student's T-test
- For covariate comparisons
  - Trafficked versus Un-trafficked AFTER Covariate effects
  - Interface Shear Resistance (Strength, Modulus & Work)
  - Linear regression on the covariate (normal stress)

Results and Analysis

Relative Density

- Statistically significant difference
- Slight increase in density with 2 years of traffic
- Un-trafficked density very similar to as-constructed

Statistic	Trafficked	Un-trafficked
Mean	99.5%	98.0%
Standard Deviation	1.3%	1.3%
p-value	0.05 for 30 degrees of freedom (df)	

Resilient Modulus

- Statistically significant difference
- Moderate increase in modulus with 2 years of traffic
- Expected as the density increased and aggregate stabilises

Statistic	Trafficked	Un-trafficked
Mean	3,675 MPa	3,158 MPa
Standard Deviation	668 MPa	371 MPa
p-value	0.04 for 30 degrees of freedom (df)	

Wheel Tracking

- Statistically significant difference
- Moderate reduction in rut potential with 2 years of traffic
- Expected as the density increase consumes rut potential

Statistic	Trafficked	Un-trafficked
Mean	1.9 mm	3.3 mm
Standard Deviation	0.6 mm	0.2 mm
p-value	< 0.01 for 6 degrees of freedom (df)	

Aggregate orientation

- Statistically significant differences
- Aggregate more aligned to horizontal after two year's traffic
- Vector Magnitude very high compared to literature

Statistic	Average Angle		Vector Magnitude	
	Trafficked	**Un-trafficked**	**Trafficked**	**Un-trafficked**
Mean	32.8°	39.8°	69.1%	59.0%
Std. Dev.	0.93°	2.73°	4.6%	6.4%
p-value	< 0.01 for 7 df		0.02 for 7 df	

Interface Shear Resistance

- Normal Stress is very significant on all with linear impact
- Traffic significant for Strength and Work
- Traffic not significant for Modulus
  - Modulus thought to be governed by interface texture

Predictor	R^2 for Regression	Traffic	
		Increase	p-value
Strength	77%	25-50%	0.01
Modulus	23%	0-5%	0.70
Work	91%	25-100%	< 0.01


Summary and Conclusions

In summary

- Two years of aircraft traffic statistically significant for all parameters except for the modulus of the interface bond
- Under heavy traffic
  - Aggregate re-orientated to a more horizontal alignment
  - Relative density increased moderately
    - Increased asphalt modulus
    - Consumed some rut potential
  - Improved aggregate embedment and bond

In conclusion

- Aircraft traffic has a substantial impact on an asphalt
- General improvement in structure and response
- Further work required to determine rate of evolution
- Where possible after resurfacing
    - Allow straight-through traffic before heavy braking
        - Closure of rapid exit taxiways after resurfacing
        - Discourage the use of heavy braking
    - Reduced risk of shear or slippage failure


THANKYOU